NEW TDRSS COMMUNICATIONS OPTIONS FOR SMALL SATELLITES

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ABSTRACT

NASA uses the Space Network, which includes the Tracking and Data Relay Satellite System (TDRSS), to provide reliable low- and high-data rate relay services between user spacecraft in Earth orbit and the ground. When compared to many past and current missions supported by the TDRSS, future user spacecraft will be extremely compact, and will have limited resources (e.g., weight, space, and DC power) available for the communications subsystem. This departure from past designs necessitates a re-evaluation of all aspects of the mission, including the enabling space and ground systems. This document provides an overview of new communications options for TDRSS support to small spacecraft missions. In particular, new transponder technologies, evolution to Ka-band frequencies, and a TDRSS Demand Access service capability are herein described. Development of these new communications options has been brought about by the Goddard Space Flight Center (GSFC) Mission Operations and Data Systems Directorate and the GSFC Engineering Directorate under the sponsorship of NASA Headquarters, Office of Space Communications.

INTRODUCTION

NASA uses the Space Network, which includes the TDRS System, to provide reliable low- and high-data rate relay services between user spacecraft in Earth orbit and the ground. TDRSS consists of several communication spacecraft at geostationary orbit as well as ground terminals located at the White Sands Complex (WSC) in White Sands, New Mexico. TDRSS provides forward service, which includes satellite and instrument commanding, and return service, which includes both science data and satellite telemetry. TDRSS provides these functions via the Single Access (SA) service, which uses high gain antennas on the TDRS to achieve data rates up to 300 Mbps, or the Multiple Access (MA) service, which uses a phased array antenna that can support commanding to one user or low-rate science data and telemetry from several users simultaneously.[1]

When compared to many past and current missions supported by the TDRSS, future user spacecraft will be extremely compact, and will have limited resources (e.g., weight, space, and DC power) available for the communications subsystem. This departure from past designs necessitates a re-evaluation of all aspects of the mission, including the enabling space and ground systems. This document provides an overview of new communications options for TDRSS support to small spacecraft missions. In particular, new transponder technologies, evolution to Ka-band frequencies, and a TDRSS Demand Access service capability are herein described. Development of these new communications options has been brought about by the Goddard Space Flight Center (GSFC) Mission Operations and Data Systems Directorate and the GSFC Engineering Directorate under the sponsorship of NASA Headquarters, Office of Space Communications.

KA-BAND CONSIDERATIONS

One part of the current re-evaluation concerns the use of higher frequency band systems, such as Ka-band, that represent a major shift in NASA's space communications frequencies. This shift is brought about, in part, by the recognition of the present and anticipated regulatory and interference pressures on NASA to move to higher frequency bands. Use of the existing communications infrastructure in ground stations and relay satellites for S, X, and Ku bands will be combined with new services in Ka-band using standardized components to yield the most cost effective means to accomplish the science mission. Figure 1 illustrates the variety of communications links which may be used.

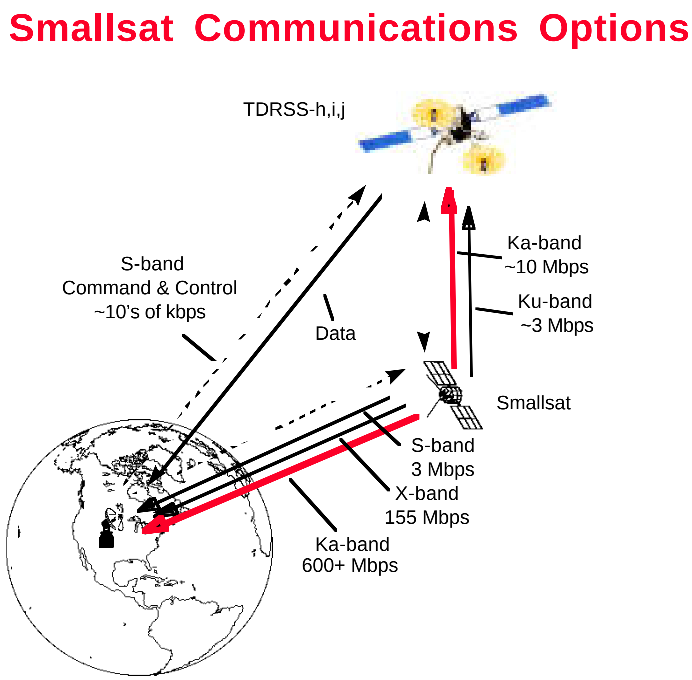

Figure 1. Near-Earth Smallsat Communications Options

Miniaturization of the spacecraft communications payload and the introduction of Ka-band operational links are the major thrusts of this program. The vision for the small spacecraft communications system is a highly integrated radio frequency subsystem that exploits recent advances in electronics devices and packaging, digital signal processing, and materials. These advances, along with new approaches to antenna design, will have a positive impact on the power, mass, volume, and cost of the communications system.

FOURTH GENERATION TDRSS TRANSPONDER

To achieve lower costs in operating these next generation spacecraft, command and housekeeping communications will be increasingly demand-driven and asynchronous. The NASA 4th generation transponder is being developed by GSFC to satisfy these requirements, while maintaining compatibility with the existing NASA S-band infrastructure. Communications direct to Earth or via TDRSS can be accomplished either by fixed schedule, as is currently done, or initiated independently by either the ground or the spacecraft using the future capability of TDRSS Demand Access. Small, low-cost, omni-directional antennas are used, with data rates varying from as low as 128 bits/second up to 3 megabits/second to existing ground stations. This technology is proposed as a standard for flight on all Earth orbiting missions, and has also been proposed for use on the New Millennium Program Earth Orbiting Missions. Figure 2 shows the improvement that can be achieved with this technology in several key performance factors compared to the 3rd Generation Transponder which is the latest standard transponder for NASA missions (Figure 3).

In addition to the relatively low-rate command and control communications described above, transfer of multi-terabit daily data streams of science data to central archives for Earth observation programs such as the EOS will be required. It is also anticipated that increasing numbers of end users such as universities will desire direct access to spacecraft instruments using low-cost ground stations. These operations will require peak data rates of tens to hundreds of megabits/second and must be accomplished with high-gain onboard antennas of a size dictated by the small dimensions of the new spacecraft. These size restrictions and the increasing international competition for RF spectrum will ultimately force all users to utilize current allocations more efficiently and develop the technology to use new frequencies such as Ka-band (25-27 GHz). This band is desirable in that it provides both wider frequency allocations for higher downlink rates and smaller antennas for a given gain due to its shorter RF wavelengths. The 25 to 27 GHz range contains overlapping allocations for both space-to-space and space-to-Earth communications links.

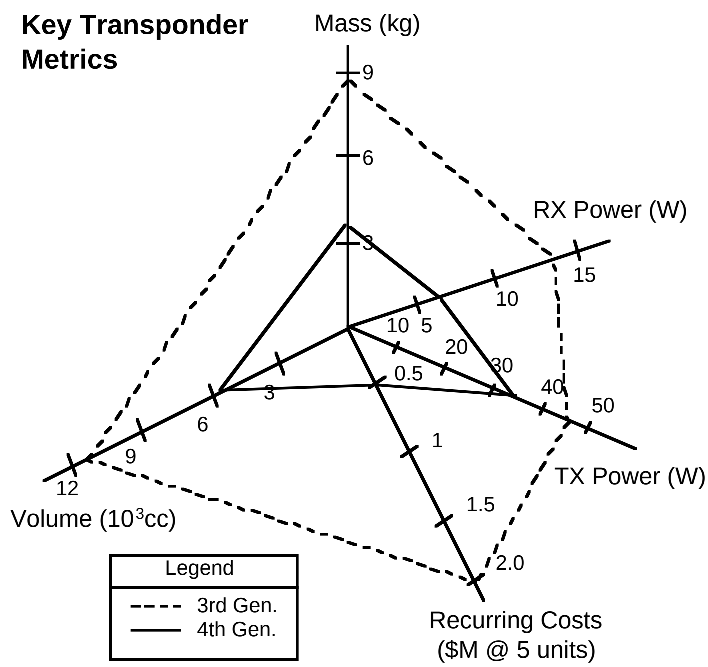

Figure 2. Expected Improvement in Performance of the NASA 4th Generation S-band Transponder (Values closer to the center of the chart indicate improved performance)

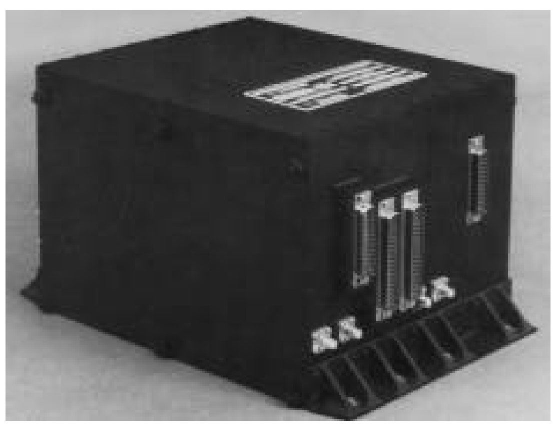

Figure 3. NASA 3rd Generation Transponder (EOS AM-1, Landsat-7)

Phased array antennas with associated high efficiency RF power amplifiers are seen as a solution to the problems associated with providing high gain for science downlinks without the deployable structures, moving parts and torque disturbances that are associated with current mechanically steered high-gain antennas. Antenna concepts being developed by GSFC can utilize current international frequency allocations to enable data returns direct to Earth at very high rates for short periods (hundreds of Megabits/second during short 10 to 15 minute overhead passes) and to White Sands via the TDRSS (approximately ten Megabits/second during up to several hundred minutes of contact opportunity per day). Figure 4 estimates the improvement in performance that can be achieved with a Ka-band system compared with NASA's Landsat-7 X-band system, which is typical of a direct to

Earth, high rate downlink system using current technology. Figure 5 illustrates one of several potential architectures for the phased array.

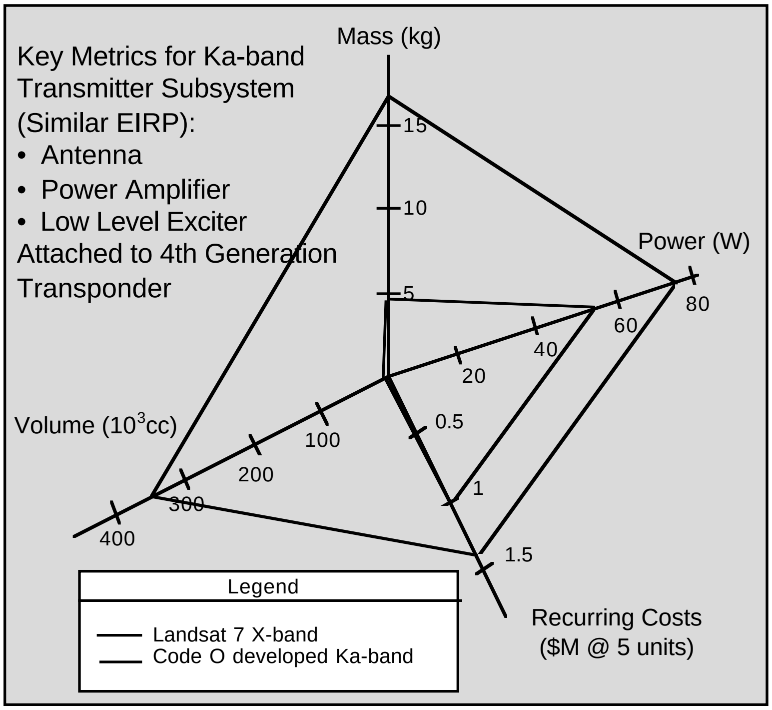

Figure 4. Expected Improvement in Characteristics of a High Data Rate Transmitter
Volume values include antenna gimbal for X-band system
(Values closer to the center of the chart indicate improved performance)

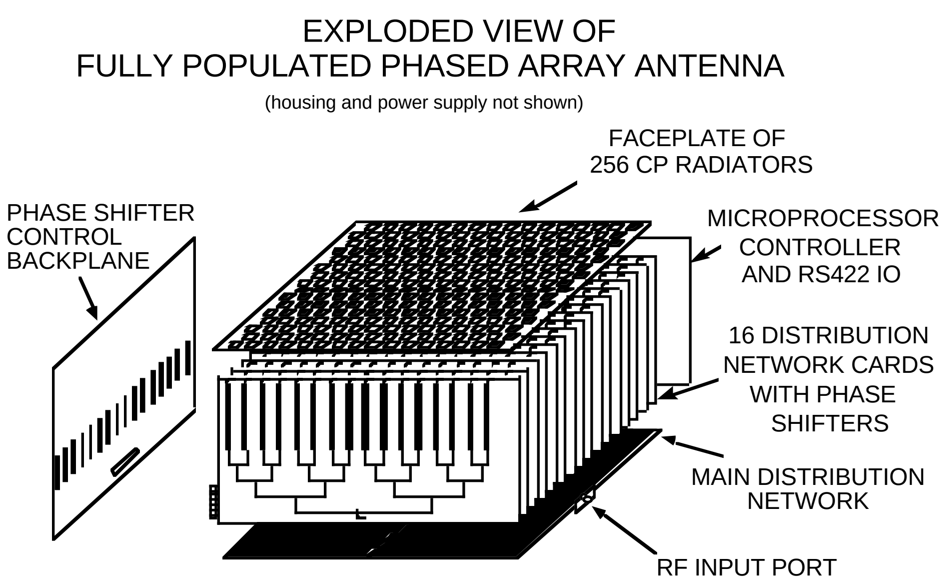

Figure 5. One of several potential phased array architectures

DEMAND ACCESS DEVELOPMENTS

Current operations of TDRSS provide access to services based on a schedule of the available communications links which is generated from user requests . Normally completed days in advance, this schedule is based upon estimates of user needs and mission event timelines. The desire to provide service to smaller missions and at reduced cost makes implementation of more efficient service allocation approaches desirable. Several promising concepts have been identified for automated service on demand that could provide substantial benefits to TDRSS users and the TDRSS Network at low cost and with no changes to existing TDRSS spacecraft. Modification of the TDRSS MA service was selected for demand access due to its ability to serve multiple users and its relative availability—the SA service is heavily scheduled for use by high-data rate users.

Demand Access service is envisioned as an automated unscheduled communication service that provides service at all times with little or no contention between users. As illustrated in Figure 6, this automated service provides forward links to user spacecraft and return links from user spacecraft to their operations control centers via the WSC. Simple modifications to the existing system can provide near real time service for a large number of users.

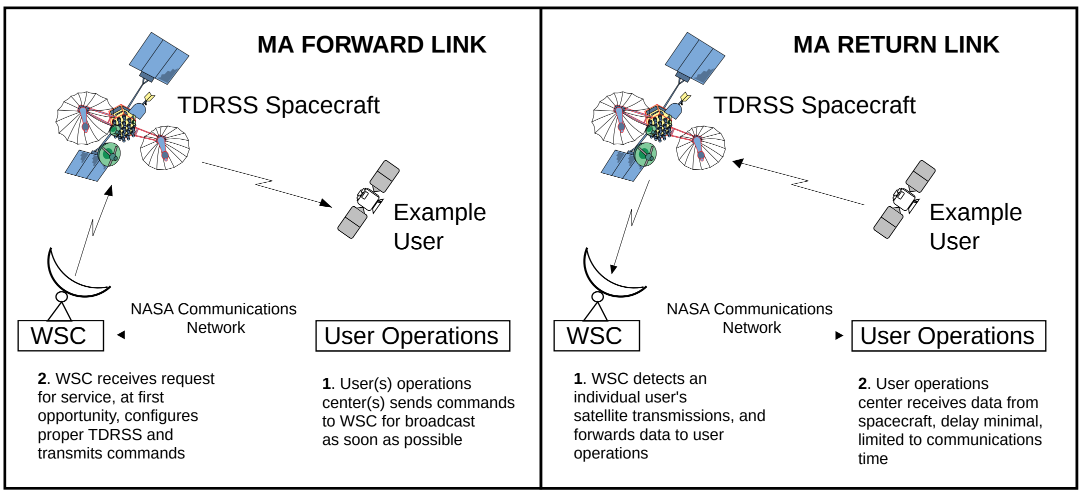

Figure 6: Demand Access Services

Some sample applications for demand access are illustrated in Figure 7. Potential services include the capability for an autonomous spacecraft to send a message notifying its operations control center of any spacecraft anomaly or science observation opportunity. Another potential capability for demand access is TDRSS service for non-space users. For example, TDRSS could be used to collect data from a large number of buoys that monitor ocean conditions. In this application, many buoys will communicate using TDRSS to send low-rate data to centers collecting the information. Demand access can assist such a service by increasing the number of users that can be accommodated by the MA return service.

While each TDRS MA return service may accommodate multiple simultaneous users, the MA forward service has only one link per TDRS. This sharing of the MA forward resource leads to possible delays in forward service. Because of the operational differences between forward and return MA services, the candidate implementations require different approaches, different modifications to the existing system, and different evaluation criteria.

For return demand access service, the primary considerations depend on hardware implementations which may allow service from any user at any time. For forward service, considerations include allocating one or more TDRS solely to demand access, or sharing some or all available MA resources between the set of users scheduled under the current system and subsequent demand access users. Assuming that demand access users would receive service on a first-come first-served basis, limitations on TDRS-user visibility and handling of emergencies must be considered.

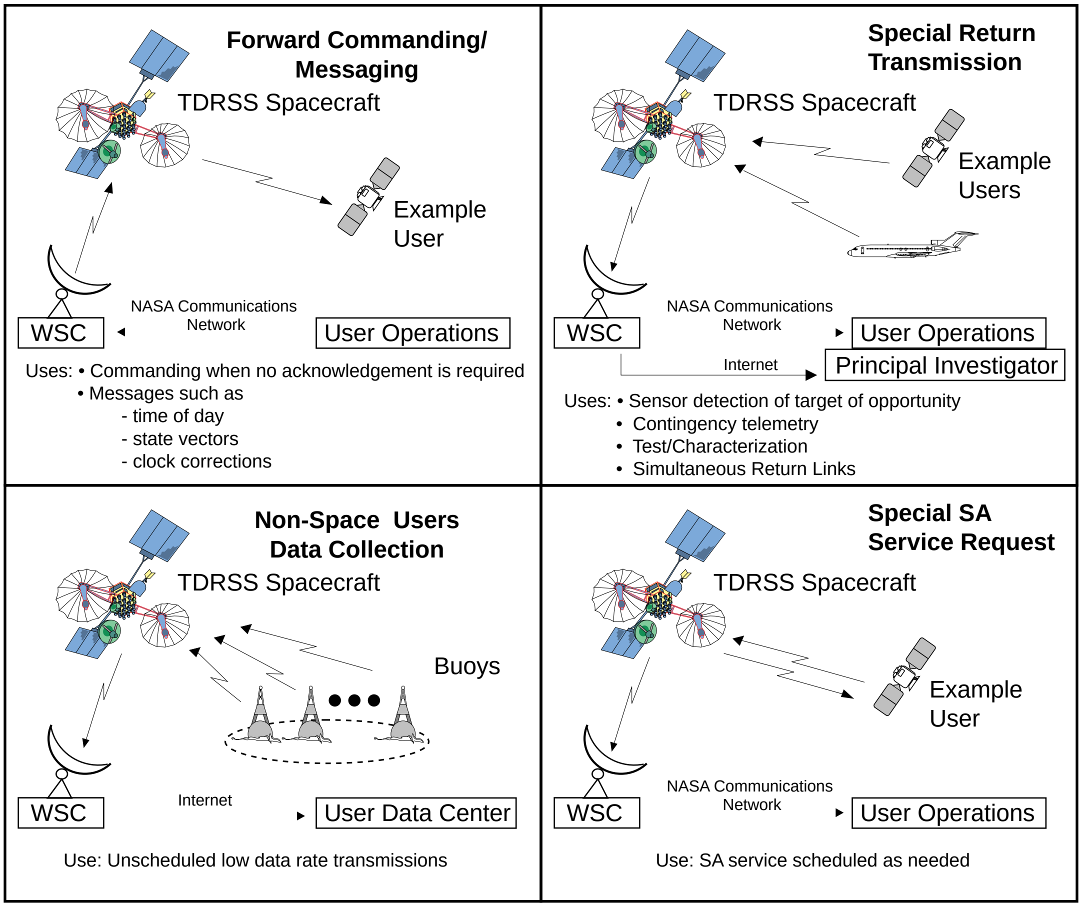

Figure 7: Candidate Demand Access Applications

MA FORWARD CONSIDERATIONS

The candidate approach for demand access MA forward service shown in Figure 8 was examined due to its operational simplicity, possible quick implementation, and efficient utilization of the existing MA forward service. This approach allows users to request a forward service whenever desired, it does not address the sharing of resources between scheduled and demand access users. The approach includes the following operations: (i) user operation control centers send command messages to a central Demand Access Processor (DAP) at any time; (ii) DAP queues messages on a first-come-first-served basis; (iii) DAP sends appropriate acknowledgments to the user operations control center; (iv) DAP creates and sends the necessary commands to configure the TDRSS system for the requested service; (v) WSC configures the TDRSS system and establishes the forward link to the appropriate user; and (vi) DAP sends the user data through the WSC and to the TDRSS spacecraft. This process substitutes service on demand for the normal advanced scheduling of services and has users transmit their data to the DAP when the request is made rather than transmitting their data directly to WSC at their scheduled time.

Message length, along with user desired wait time, becomes a factor as loading of the system increases. Simulations of a dedicated TDRS demand access scenario indicate that users quickly receive more of their requested services, if those services are kept short. For the single TDRSS spacecraft case, several observations include: (i) messages of up to 2.5 minute duration per orbit per user can be accommodated with little or no queue waiting time (with < 1% probability that waiting time exceeds 2.5 minutes); (ii) waiting time increases to a maximum of 15 minutes for messages of 5 minute duration per orbit; and (iii) the queue grows unacceptably for message durations > 5 minutes with instability occurring for message durations exceeding 8 minutes.

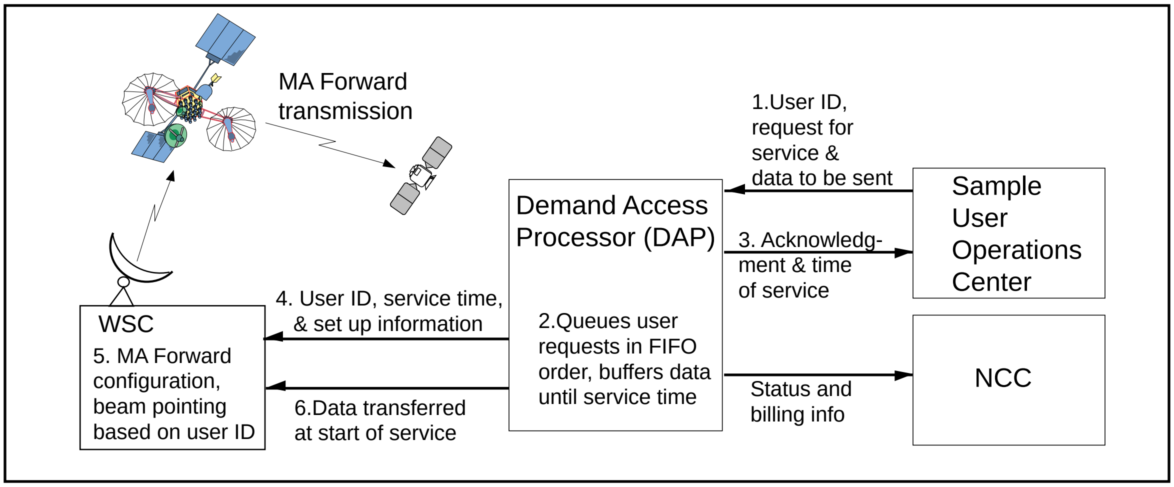

Figure 8: Candidate Approach for MA Forward Demand Access

If an implementation involves allowing demand access users to further fill a scheduled TDRSS, then other detailed considerations become important for MA forward service. Whether or not users are provided a list of open slots in the schedule, may influence the number of submissions that a user must make to receive service. Timing of the empty schedule's availability, its constancy over time, and the allowed time between demand access request submission and requested service time may all influence a demand access user's satisfaction.

Simulation of scheduled users requesting additional services of their normal length (user dependent - ranging from 10 - 16 minutes per orbit) indicates that a two TDRS schedule which is approximately 60% full can accommodate several additional demand access services per day per user with little or no service delay. Assumptions in this simulation included that users knew the unused schedule time slots, their own scheduled service times, and their own visibilities to the relay satellites. This information meant that users would not request a service when it had either no chance of success or would coincide with their own scheduled service.

Current MA forward implementation plans are proceeding in a phased fashion, beginning with the planned sharing of resources between scheduled and demand access users. It is anticipated that demand access users will have the unscheduled times available to them. A set of ideal requirements is under development. User inputs, including user preferred methods of demand access request submissions are under consideration.

MA RETURN CONSIDERATIONS

Two primary candidate implementations have been examined that provide MA return demand access service to different groups of TDRSS users. Both implementations do not require large changes to the current TDRSS system, but they do use additional hardware components. Because each implementation benefits different types of users, and TDRSS MA return service allows multiple users to access the system simultaneously, return demand access can accommodate a large number of users with a high level of satisfaction. Depending on the number of users, these implementations may provide continuous service to each user, so that a dedicated, rather than demand access, service is actually provided.

The first candidate implementation uses dedicated TDRSS MA return antenna beams to track user spacecraft, thus providing the opportunity for user spacecraft to return data any time they are in view of a TDRS. If three widely spaced TDRS are used, continuous coverage can be provided. A key requirement for this approach is that enough beamformers and demodulators be available at WSC to serve all demand access users. Since WSC equipment chains are dedicated to each TDRSS spacecraft, the possibility of an uneven distribution of users in view to a specific TDRSS spacecraft means that the total number of required beamformers and demodulators exceeds the number of users.

The second approach for demand access return service involves the use of a set of stationary MA return beams to cover specific regions within the field-of-view of a TDRSS spacecraft. A set of low-rate demodulators is provided for each beam with each demodulator matched to a user-unique code. As in the first approach, full random access transmissions by TDRSS users are supported; however, because the users are relatively fixed, no changes need to be implemented as different users are serviced within the same beam.. This approach to sharing a single MA antenna beam among multiple users can provide TDRSS service to non-space users at minimal impact to the existing TDRSS infrastructure. Ocean buoys, for atmospheric and oceanic monitoring purposes, could transmit anytime for routine memory dumps or special weather alerts. As in the first return demand access implementation, each user is assigned a unique code that would be demodulated by a bank of demodulators.

Overall, the increased operational flexibility and reduction in scheduling costs is expected to reduce the long term mission operations costs of the majority of users of the TDRSS Demand Access service.

SUMMARY

In summary, the NASA vision of space exploration in the next decade and beyond is predicated on the development of small, low cost spacecraft. The technology initiatives described herein have been designed to expand the range of communications options available to small spacecraft, from the global coverage and real time access of TDRSS to the high rate science data reception capability of low cost Ka-Band ground stations or an optimal combination of both. GSFC's development activities are oriented toward addressing spacecraft and systems technologies which contribute significantly to the vision of lower cost space exploration.

REFERENCES

1. D. Brandel, W. Watson, & A. Weinberg, "NASA's Advanced Tracking and Data Relay Satellite System for the Years 2000 and Beyond," *Proceedings of the IEEE*, vol. 78, p. 1141-1151, July 1990